Neutron Emission Spectra from Actinides

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We have carried out a systematic analysis of the nuclear reaction data for all isotopes of uranium. In the course of this work, we have addressed a long-standing problem in adequately describing neutron emission spectra emanating from neutron-induced reactions on actinides. The problem is manifested in our failure to adequately calculate measurements of neutron leakage as a function of time-of-flight following the introduction of 14-MeV neutron pulses into the center of uranium or plutonium spheres [1]. Additionally, this problem is seen in attempting to reproduce measurements of neutron emission spectra [2].

This problem is illustrated in Fig. 1, where we show angle-integrated neutron emission spectra from a ^{238}U target bombarded by 14.05-MeV neutrons. The red dashed curve ("Maslov, 2003") is a calculation that includes compound nucleus and pre-equilibrium theory contributions, as well as direct reactions to known low-lying states in ^{238}U below an excitation energy of 1 MeV. The problem that occurs between emission neutron energies 9 and 13 MeV results from the omission of direct reaction contributions to collective states at excitation energies 1–4 MeV that have not been measured but are known to exist from theoretical considerations [3]. A similar problem occurs to a lesser extent in the ENDF/B-VI curve (blue short dashes), in which these missing states have been only partially taken into account.

To solve this problem, we postulate the existence of a set of states at excitation energies between 1 and 4 MeV having spin and parity 3^- and 2^+ that approximate the unmeasured collective states. We perform coupled-channels optical model calculations with the code ECIS96 [4] for each of the assumed states and use the Baba data [2] to determine the spin, parity, and deformation parameters of each assumed state. With these parameters assigned, we then can calculate cross sections and angular distributions for these states for any incident neutron energies and outgoing emission angles. The results of

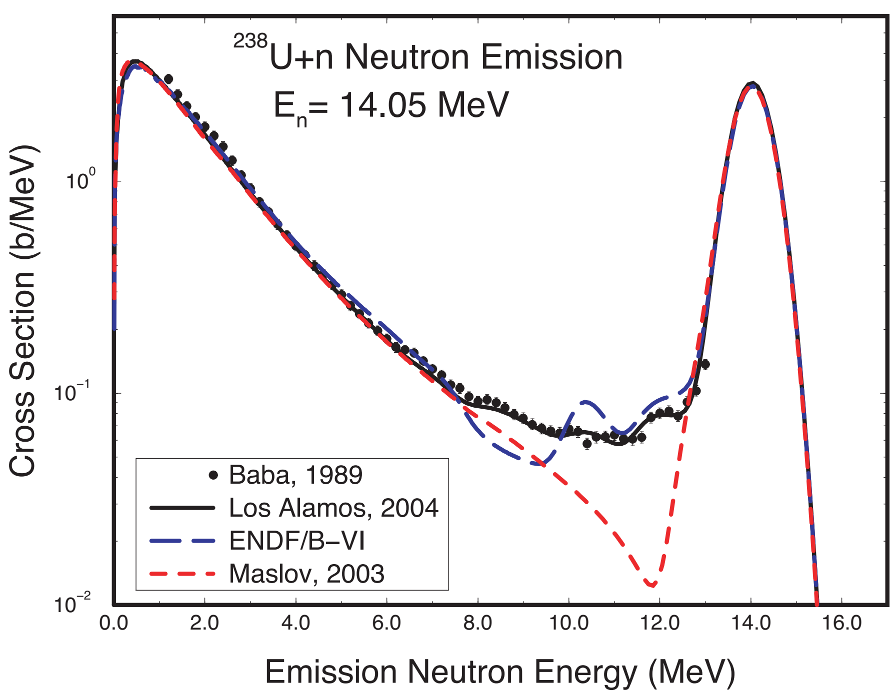

Figure 1— ***Angle-integrated neutron emission spectra from 14-MeV neutron reactions on ^{238}U.***

our calculations for ^{238}U at 14 MeV are shown by the black solid curve in Fig. 1 (“Los Alamos, 2004”), which essentially coincides with the experimental data. These assumptions lead to significantly improved calculations of neutron emission spectra from ^{238}U at all incident neutron energies and emission angles.

To address the problem of poor simulations of time-of-flight neutron distributions from pulsed-sphere measurements, we applied these same ideas to calculations of neutron emission from a ^{239}Pu target by assuming similar states in this nucleus. While there are no direct measurements of neutron emission cross-sections from ^{239}Pu, we compare the results of our calculations for ^{239}Pu (black solid curve) with the Baba ^{238}U measurements [2] and prior evaluation (red dashed curve) in Fig. 2. These results are encouraging, but to directly test the new analysis, we simulated the 14-MeV time-of-flight neutron emission measurements from a ^{239}Pu sphere with the MCNP Monte Carlo code using our ^{239}Pu evaluation. The results are compared in Fig. 3, where the black solid curve represents the experimental data, the red short-dashed curve is the MCNP simulation with the previous evaluation, and the blue long-dashed curve is our new result. The improvement in reproduction of the measurements is significant, and we plan to broaden our analysis in the future to cover all important actinides.

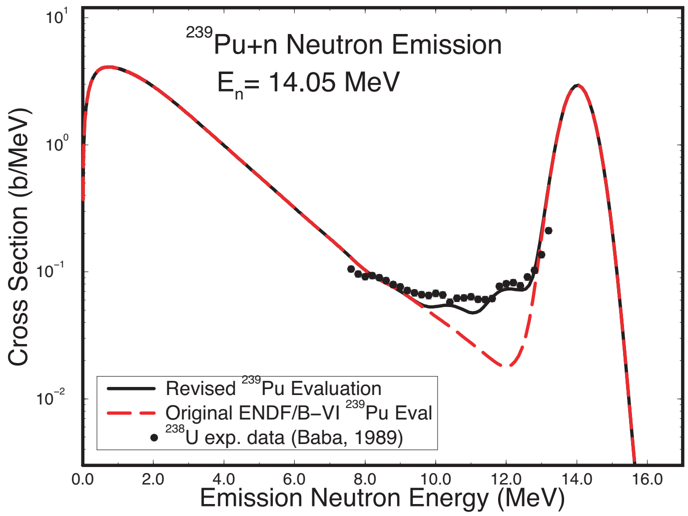

Figure 2— ***Angle-integrated neutron emission spectra from 14-MeV neutron reactions on*** ^{239}***Pu.***

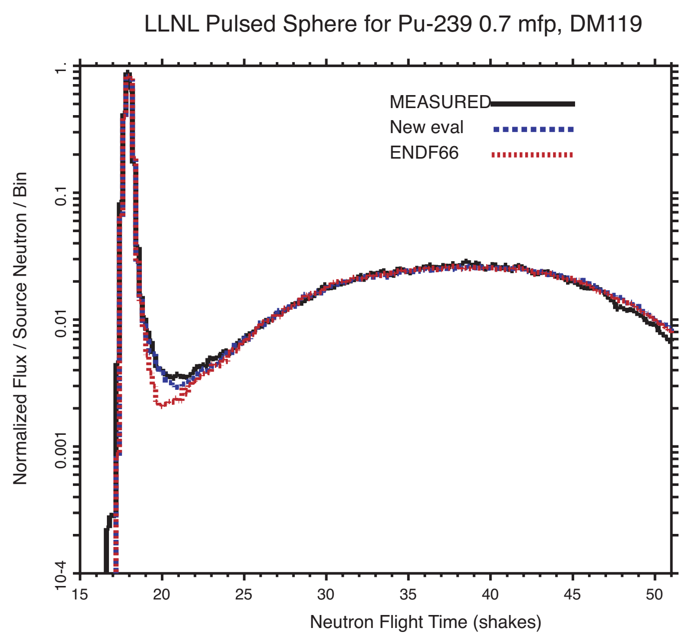

Figure 3— ***Time-of-flight spectrum of leakage neutrons from a sphere of*** ^{239}***Pu pulsed with 14-MeV neutrons at its center.***

[1] L.F. Hansen, C. Wong, T.T. Komoto, B.A. Pohl, E. Goldberg, R.J. Howerton, and W.W. Webster, *Nucl. Sci. Eng.* **72**, 35 (1979).

[2] M. Baba, H. Wakabayashi, N. Itoh, K. Maeda, and N. Hirakawa, Japanese Atomic Energy Research Institute report JAERI-M-89-143 [INDC(JPN)-129] (1989).

[3] A. Marcinkowski, P. Demetriou,, and P.E. Hodgson, *J. Phys. G [Nucl. & Part. Phys.]* **22**, 1219 (1996).

[4] J. Raynal, “Notes on ECIS94,” Centre d’Etudes Nucleaires (Saclay) report CEA-N-2772 (1994).